Optimal Deployment of Drifting Acoustic Sensors: Sensitivity of Lagrangian Coherent Structure Boundaries to Model Uncertainty

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LONG-TERM GOALS

Our long-term goal is to provide a template for the launch locations of drifting Lagrangian measurement platforms that will maximize the amount of environmental information provided by a necessarily limited number of observational resources. By coupling the geometric analysis of fluid parcel movement provided by the identification of Lagrangian coherent structure boundaries with high resolution, Lagrangian data assimilating numerical ocean models, we ultimately seek the accurate prediction of particle trajectories in the ocean. The overall goal is to develop a robust set Lagrangian analysis tools to provide synoptic information on the fate of drifting sensor packages.

OBJECTIVES

Three specific objectives were defined for F06 funding:

- Participation in the DART observational program to develop and test model-based directed drifter launch protocols in the context of NCOM Adriatic forecasts.
- Determination of the sensitivity of computed Lagrangian coherent structure boundaries to perturbations in the spatial and temporal resolution of input Eulerian model data.
- Lagrangian analysis of HYCOM hindcasts in the Gulf of Mexico.

APPROACH

Optimal deployment strategies for drifting acoustic arrays will rely heavily on precise knowledge of the location, in both time and space, of Lagrangian coherent structure boundaries computed by post-processing numerical Eulerian velocity data. A fundamental question concerning the operational use of such Lagrangian analyses is the sensitivity of the computed structures to inherent uncertainties in the model prediction of the Eulerian velocity field. Objective assessment of the level of Lagrangian uncertainty produced by current ocean models requires the development of metrics that will allow quantitative comparison of the extended Lagrangian boundary curves resulting from ensembles of model perturbations. Systematic analysis of the sensitivity of computed LCS boundaries to various levels of model uncertainty will determine the model precision and fidelity needed to reliably employ LCS boundary information in an operational observational experiment. The approach is based primarily on application of available Lagrangian metrics identifying particle transport pathways to velocity fields produced by high-resolution, data-assimilating circulation models.

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Work on the first and second objectives involves a collaborative effort with Ozgokmen, Griffa and associates at the University of Miami and CNRS, Italy as well as observational oceanographers participating in the DART program. This work relies on the analysis of various outputs from a 1km resolution, fully data-assimilating NCOM model of the Adriatic basin provided by Paul Martin of NRL.

The third objective involves oceanographers at the University of Delaware, Kirwan and Lipphardt, and is an extension of previous analyses of a POM-based Gulf of Mexico simulation (provided by Kantha at U. Col.) to high resolution HYCOM model output in the same basin. A. Srinivasan at FSU and RSMAS has provided model data and HYCOM guidance.

WORK COMPLETED

1) Acceptance of a paper documenting the applicability of model based Lagrangian metrics to drifter launch strategies in a real-time observational setting. (Haza et al., 2007)

2) Completion of sensitivity analysis of Lagrangian structures in the context of the NCOM Adriatic model. Manuscript presently in revision. (Haza et al., 2007a)

3) Initial analysis of Loop Current Eddies *Sargassum* and *Titanic* in HYCOM Gulf of Mexico control model output.

RESULTS

To test the feasibility and practical limitations of using Lagrangian analyses of ocean model forecasts to direct drifter launches in real-time, NCOM model output of the Adriatic Sea was used to predict Lagrangian coherent structure boundaries, quantified by finite-size Lyapunov exponents (FSLE), for flow features in the region of the Gargano Peninsula during the course of the DART observational program during March 2006. FSLE fields computed from forty-eight hour model forecasts of the surface velocity indicate distinct regions of high relative drifter dispersion. Model predictions of the FSLE fields used to direct the launches and the observed drifter trajectories are shown in Figure 1 for three days during March 2006. For two of the three cases (March 16 and 23), the observed trajectories separated at locations and along directions closely approximated by those predicted from the model FSLE fields. In the third case, which involved a delay in launching due to operational considerations, the model predictions on the delayed launch day indicate a lack of strong Lagrangian boundary signature in the FSLE fields between the drifter pair. In this case, the observed drifters show much smaller separation.

As shown in the lower panel of Figure 1, there are considerable differences between individual drifter observations and trajectory envelopes computed from ensembles of synthetic drifters. However, the experiment confirms the model's ability to approximate the location and shape of energetic flow features (quantified here in terms of FSLE fields) controlling the near-time fate of quasi-Lagrangian particles. The results show that such information can be used to direct the launch of pairs of floating instruments to either maximize or minimize future separation. Perhaps most importantly, the results clearly indicate that the NCOM model is capable of producing surface velocity fields that satisfactorily predict geometric properties of the Lagrangian transport in the Adriatic on short (1-3) day time scales.

To investigate the sensitivity of both the geometry of Lagrangian structure boundaries and their strength to errors and averages in the input Eulerian fields, synthetic drifter trajectories computed from the NCOM Adriatic were used to investigate the scaling of relative dispersion and the distribution of Finite Scale Lyapunov Exponent fields in the Adriatic. The effects of varying degrees of spatial and temporal filtering of the input Eulerian velocity fields on the Lagrangian statistics were investigated in order to assess the sensitivity of such statistics to model error.

Given hourly snapshots of surface NCOM model output on a 1km x 1km spatial grid, new velocity fields were produced by (1) running time averages over specified averaging windows, or (2) spatial convolution with Gaussian filters of varying spatial extent. Synthetic drifter trajectories computed from the time or space smoothed fields were then calculated. The FSLE, a robust measure of relative particle dispersion, was used as the primary diagnostic for comparison.

As shown in Figure 2, the FSLE curves show power law scaling with separation distance which indicates that the relative dispersion in the model Adriatic circulation is generally super-diffusive, scaling ballistically or super-ballistically. This result is in close agreement with existing Lagrangian observations from a limited set of drifters. The super-diffusive scaling implies the importance of structure in the underlying velocity field for this flow. All indications are that the large-scale dispersion is dominated by persistent separation regions and the controlling influence of the Western Adriatic Current.

A comparison of the top and bottom panels of Figure 2 clearly shows that temporal filtering with averaging windows up to monthly time scales only affects the relative dispersion at scales smaller than 20 km without altering the overall scaling regime. The case of spatial smoothing is quite different. As shown in Figure 3, spatial smoothing at scales as small as 5 km significantly reduces relative dispersion at all scales up to 100 km.

The effect of the two averaging operators on the resulting distribution of FSLE structures across initial conditions is shown in Figure 3. Here the impact of the two operators is perhaps surprisingly different than what might be expected from the overall FSLE scaling statistics shown in Figure 2. All maps clearly indicate the importance of the Western Adriatic Current in the dispersion. At the fixed, 30 km dispersion scale considered in the figure, the effect of temporal filtering is to remove the tangling caused by time dependent meanders, eddies and filaments in this region. The details of the transport pathways in the WAC are considerably changed for smoothing windows as short as 1.5 days which is a typical smoothing window for observed drifter trajectories to remove inertial oscillations. For longer time filters, what remains of the FSLE structure is confined to the mean edges of the WAC and may be associated with persistant, distinct regions of high strain. On the other hand, spatial filtering has no effect on the time dependence of important mixing features with larger spatial scales. As shown in the lower left panel of Figure 3, averaging over 2.5 grid cells (2.5 km) leaves the FSLE fields virtually unchanged. Indeed, the shape of most of the features observed in the full model fields persist up to spatial filter scales as large as 5 km.

IMPACT/APPLICATIONS

The combined use of Lagrangian structure metrics (here the FSLE) in conjunction with high-resolution, realistic coastal circulation models has been shown to be a feasible approach to the design of real-time directed drifter launch protocols in actual observational programs.

The FSLE fields computed in the NCOM Adriatic model have been shown to be robust to model uncertainty at the smallest time and space scales. The map of Lagrangian structures controlling transport and mixing in the Adriatic clearly shows the importance of WAC dynamics.

RELATED PROJECTS

Theoretical and numerical tools developed under this effort will directly inform research on constructing flow-based control algorithms for autonomous ocean surveillance and observation systems funded under ONR Grant N000140710588, PI Poje.

The work described here is part of a continuing collaborative effort and intersects with:

Predictability of particle trajectories in the ocean, ONR, PI: T.M. Özgökmen, N00014-05-1-0095.

Model Assessment and Deployment Strategies for Drifting Instruments, ONR, PI: A.D. Kirwan, N0014-00-0019

Lagrangian Turbulence and Transport in Semi-Enclosed Basins and Coastal Regions, PI: A. Griffa, N00014-05-1-0094.

PUBLICATIONS

Haza, A. C., A. Griffa, P. Martin, A. Molcard, T. M. Ozgokmen, A. C. Po je, R. Barbanti, J. W. Book, P. M. Poulain, M. Rixen, P. Zanasca, 2007: Model-based directed drifter launches in the Adriatic Sea: Results from the DART Experiment, Geophys. Res. Lett., 34, doi:10.1029/2007GL029634.

Haza, A. C., A.C. Poje, T. M. Ozgokmen and P. Martin, Relative dispersion from a high-resolution ocean model: of the Adriatic Sea. *Ocean Modeling*, in revision, 2007.

Lipphardt, B.L., A.C. Poje, A.D. Kirwan, L. M. Zweng, & , L. Kantha, Sudden Death of Loop Current Rings in a Gulf of Mexico model. *Journal of Marine Research*, in revision, 2007.

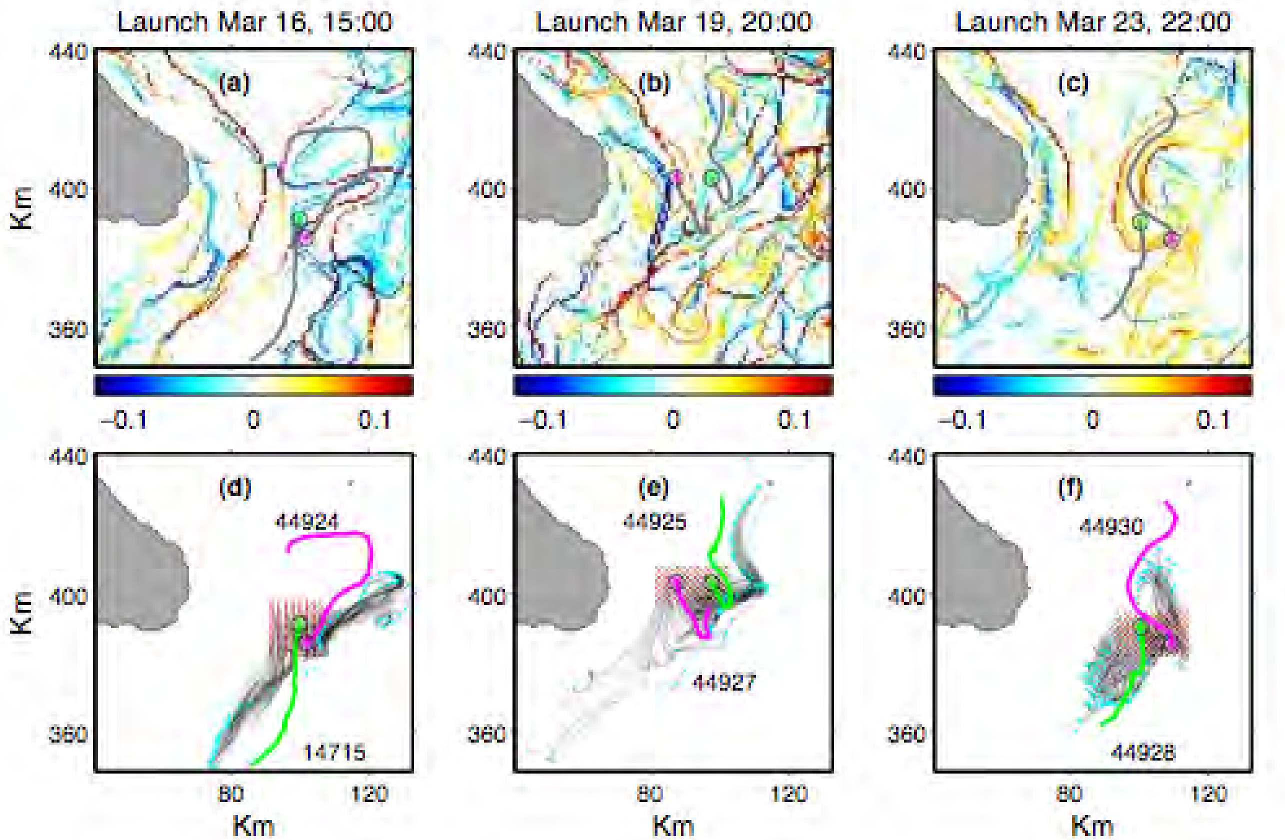

Figure 1: The initial 2-day trajectories for real (gray: upper panels, green and purple: lower panels) drifters launched on March 16, March 19 and March 23. Superimposed are the FSLE computed at launch time (a)-(c), and synthetic drifters released in regular arrays (d)-(f). Red (blue) dots indicate initial (final) positions of the synthetic drifters.

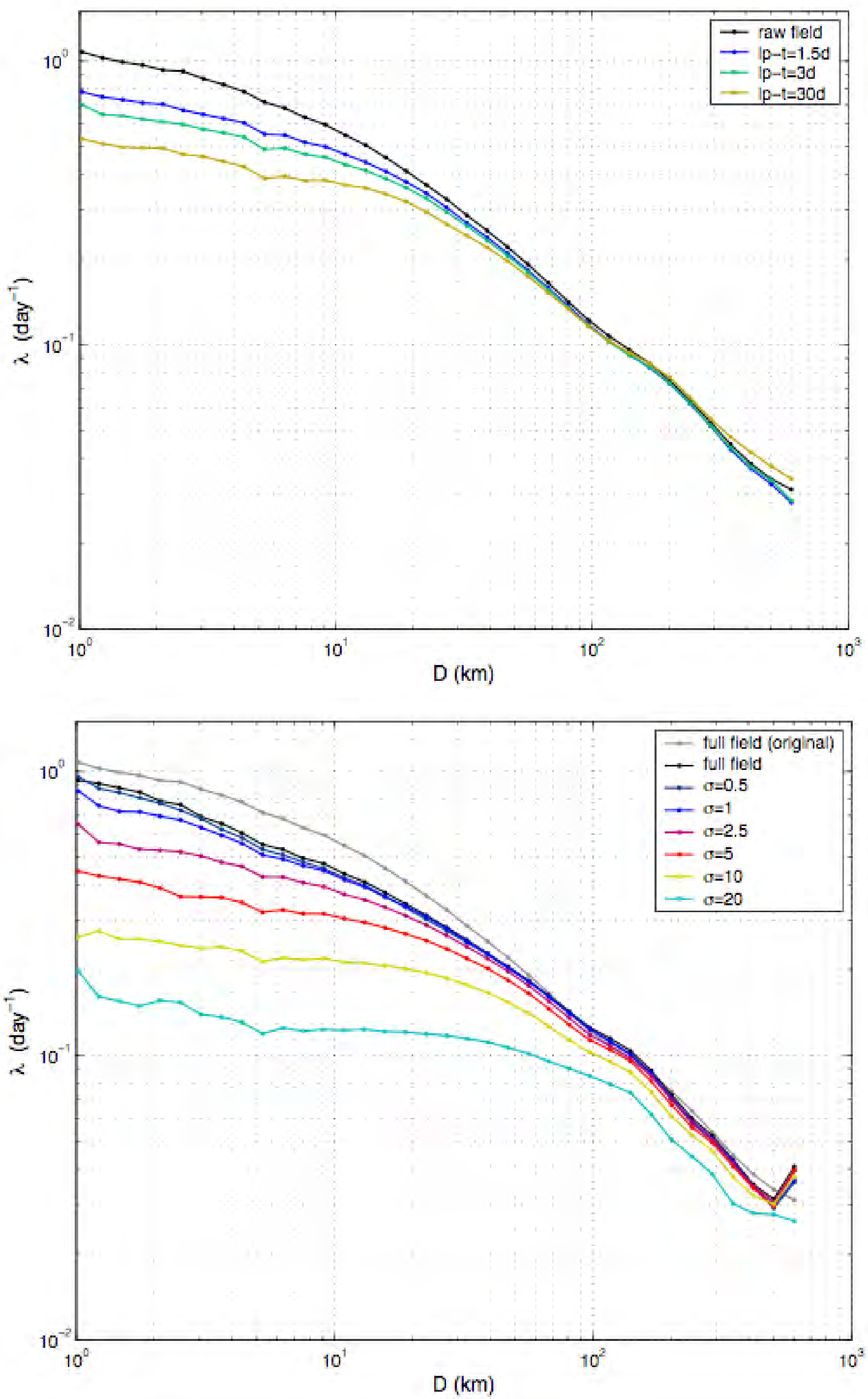

Figure 2: The Finite-Scale Lyapunov results for synthetic drifters launched in NCOM model flow showing the effect of successively longer time averaging of the model output on the resulting Lagrangian data (top panel) and the resulting effects of spatial averaging (lower panel). Spatial smoothing at scales as small as 5 km results in an appreciable impact on dispersion at scales as large as 100 km.

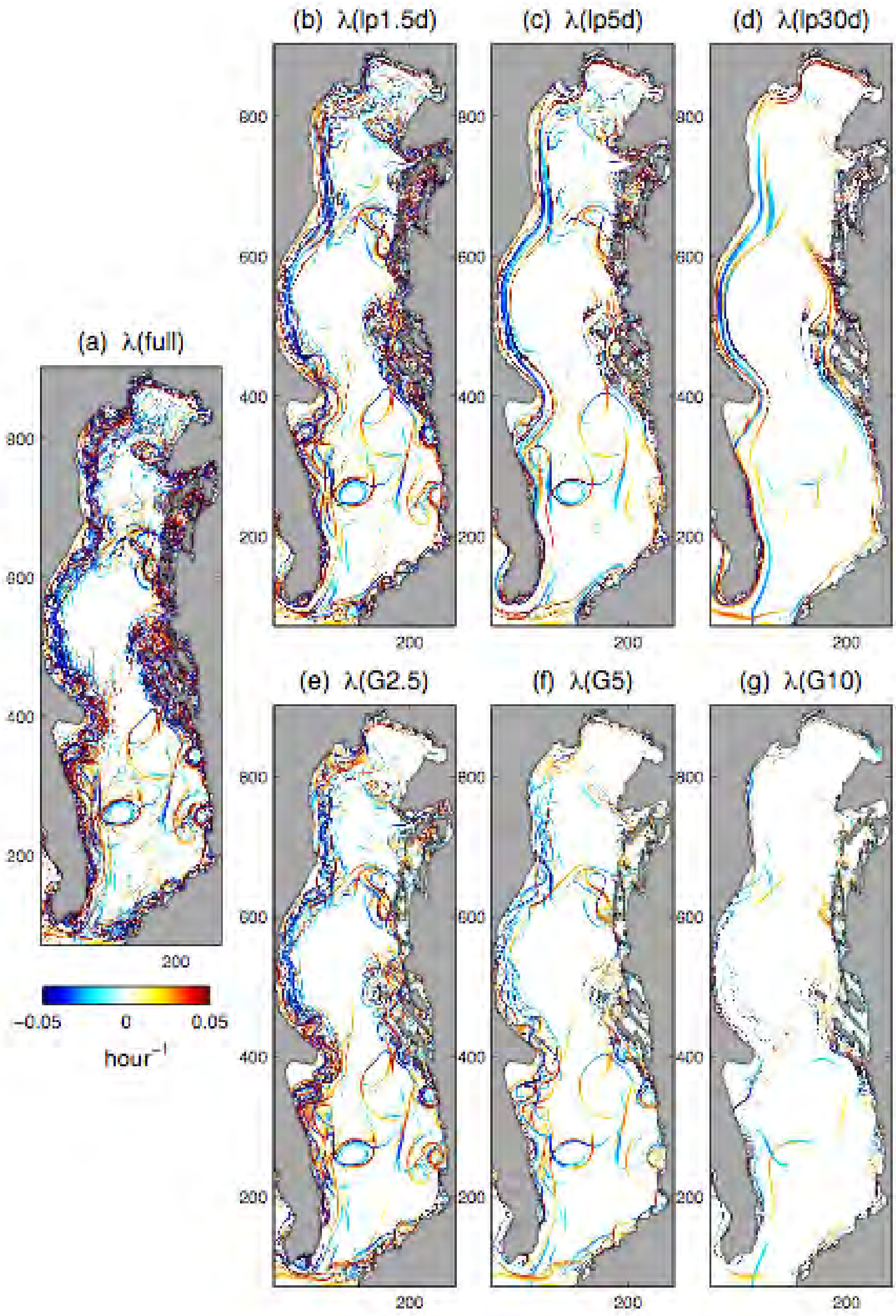

Figure 3: Spatial distribution of FSLEs forward six days in time starting from September 12, 2002 (positive, red) and backward six days in time (negative, blue) calculated with initial pair distances of .45 km. The curves show the inverse of the time required for a particle pairs to separate a distance of 30 km. The effect of running time averages of the model velocity field are shown on top while results for three different spatial smoothings are shown below.